CURRENT SHEATH DYNAMICS AND MAGNETOSONIC OSCILLATIONS IN MAGNETOPLASMAS

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The dynamics of a current sheath are important in the design and evaluation of many plasma propulsion concepts, magnetohydrodynamic power generation, fusion type thermonuclear reactor concepts, and other devices where ionized gas conducts large current densities. Knowledge of the distribution of currents and the formation of current sheaths in a plasma is basic to stability studies.

In Section I an experimental study of the dynamics of a current sheath and possible magnetosonic oscillations which result from the current sheath moving in an external magnetic field is described. Section II presents an analytical study initiated on the formation and dynamics of a current sheath in a circular cylindrical geometry. An introduction to the study of finite resistivity instabilities is also given in Section II.

I. Experimental Studies of the Dynamics of a Current Sheath and Magnetosonic Oscillations

A. Introduction

Presently, the dynamical behavior of a current sheath formed in a preionized hydrogenic plasma, accelerated by $\vec{J} \times \vec{B}$ forces, and moving

through a steady, stabilizing magnetic field is being investigated. An experimental arrangement using a stabilized inverse pinch has been designed, constructed, and partially tested. Also, magnetosonic oscillations of the current sheath which are predicted by numerical solutions of an equation of motion based on the "snow-plow" model for the current sheath are presently being searched for using small magnetic probes inserted into the discharge tube.

In the next four subsections of this report, Sections B, C, D, and E, the laboratory equipment required to produce and investigate the dynamic properties of a current sheath in a steady, stabilizing field is outlined. Two major problems to be overcome in the study of a current sheath are: (1) the problem of preionization and (2) the problem of impurities. In the next section, Section B, the production of a current sheath from a cold hydrogenic gas at micron pressures is described. Several methods of preionization are discussed, and the main acceleration is briefly described. The third section, Section C, discusses the problem of obtaining a clean hydrogenic plasma. The fourth section describes diagnostic methods in general and outlines the diagnostic equipment to be used. The parameters to be measured are described in Section D also. The last section, Section E, of this experimental portion will describe in some detail additional electronic and vacuum equipment presently being developed.

B. Producing a Current Sheath

In order to study the dynamics of a current sheath and possible magnetosonic oscillations, a method for obtaining a reproduceable current sheath in a crossed magnetic field from a cold hydrogenic gas must be

realized. Before a current sheath will readily form in a hydrogenic gas, the gas must be preionized in order to make the electrical conductivity large.

(1) Preionization

The cold hydrogenic gas may be ionized to various degrees by one or more of several methods: e.g. radio frequency discharges, direct current discharges, shock waves, and kilocycle linear discharges.

A low power (less than 200 watts) radio frequency transmitter has been used to study possible radio frequency breakdown and weak preionization. When the radio frequency power is coupled into the discharge tube through metal bands around the glass tube and a stabilizing magnetic field of 3 to 4 kilogauss obtained from an electromagnet is applied normal to the metal bands, the radio frequency ionization method is only moderately successful.

A kilocycle linear discharge which uses several cycles of a slow, sinusoidally varying, capacitor discharge of several tens of thousands amperes peak value applied to the electrodes of the discharge tube has been designed and partially assembled. A portion of a fast (80 kc) capacitor bank has been modified to give a ringing frequency of approximately 10 kc by adding a 20 to 30 microhenry external inductor.

Another possible method of preionization that is being considered is that of a 2 megacycle, 60 joule, superfast, capacitor bank which has been constructed and used for preheating a different experiment in our laboratory.

Even before applying the linear preionizing discharges, some initial "seeding" of ions and electrons may be accomplished by using

low power radio frequency or direct low current discharges.

(2) Main Acceleration

After a fairly highly ionized gas has been formed by preionization, the main current is applied to form the current sheath in the inverse pinch geometry.

A current with a peak value of approximately 100,000 amperes and a ringing frequency of 60 kc to 80 kc is used to form the current sheath in the preionized gas. (The electrical equipment for the main acceleration will be described in more detail in a later section, Section E.2.) The $\vec{J} \times \vec{B}$ forces resulting from currents in the plasma and magnetic fields set up by the pinching current drives the current sheath formed at the center of a cylindrical discharge tube, near a hard core, outward with velocities of the order of 10^6 cm/sec. Thus, a <u>dynamic</u> current sheath is produced.

Insufficient preionization, when using only a low power radio frequency oscillator, does not result in a reproduceable current sheath. The linear discharge preionization solves this problem.

C. Obtaining a Moderately Clean Hydrogenic Discharge

In order to have a moderately clean hydrogenic plasma so as to be able to study the dynamics of a current sheath of known composition, a base pressure of 10^{-5} mm Hg or better is required before the hydrogenic gas is leaked into the system. The effect of impurities on the formation (or lack of formation) of a current sheath and its behavior is very closely related to the amount of impurities through the differing electrical conductivities.

At the present time, a two-stage mechanical vacuum pump and a three-stage glass, oil diffusion pump are employed in the system to

attempt to get the required base pressures. (Further discussed in Section E.4.) The discharge tube now being tested is not bakeable since organic materials are used to make vacuum seals and electrical insulations.

D. Diagnostics for Dynamical Current Sheath and Magnetosonic Oscillations

(1) General

There are many tried and proven methods to study dynamic plasmas: e.g. magnetic probes, diamagnetic loops, Langmuir probes, microwave reflection, scattering, transmission, and radiation techniques, spectroscopy, and high-speed photography are but a few of the commonly used diagnostic methods.

(2) Magnetic Probes

Presently, magnetic probes consisting of small coils of about 20 turns each of #36 enameled wire wound on a machined nylon form 50 mils diameter are being used to probe the plasma and study the current sheath. The signal generated in the coil of wire on the probe, which varies as dB/dt, is sent through a passive electronic RC integrator to give the various magnetic fields B_θ, B_z, and B_r.

From the B_θ, B_z, and B_r measurements, the current sheath's motion (position and velocity) can be determined. Also, by using the measured magnetic fields and Maxwell's electromagnetic field equations, the current distribution can be calculated.

(3) Other Possible Diagnostics

Several other diagnostic methods are now being considered for future development. The possibility of making use of the emf generated

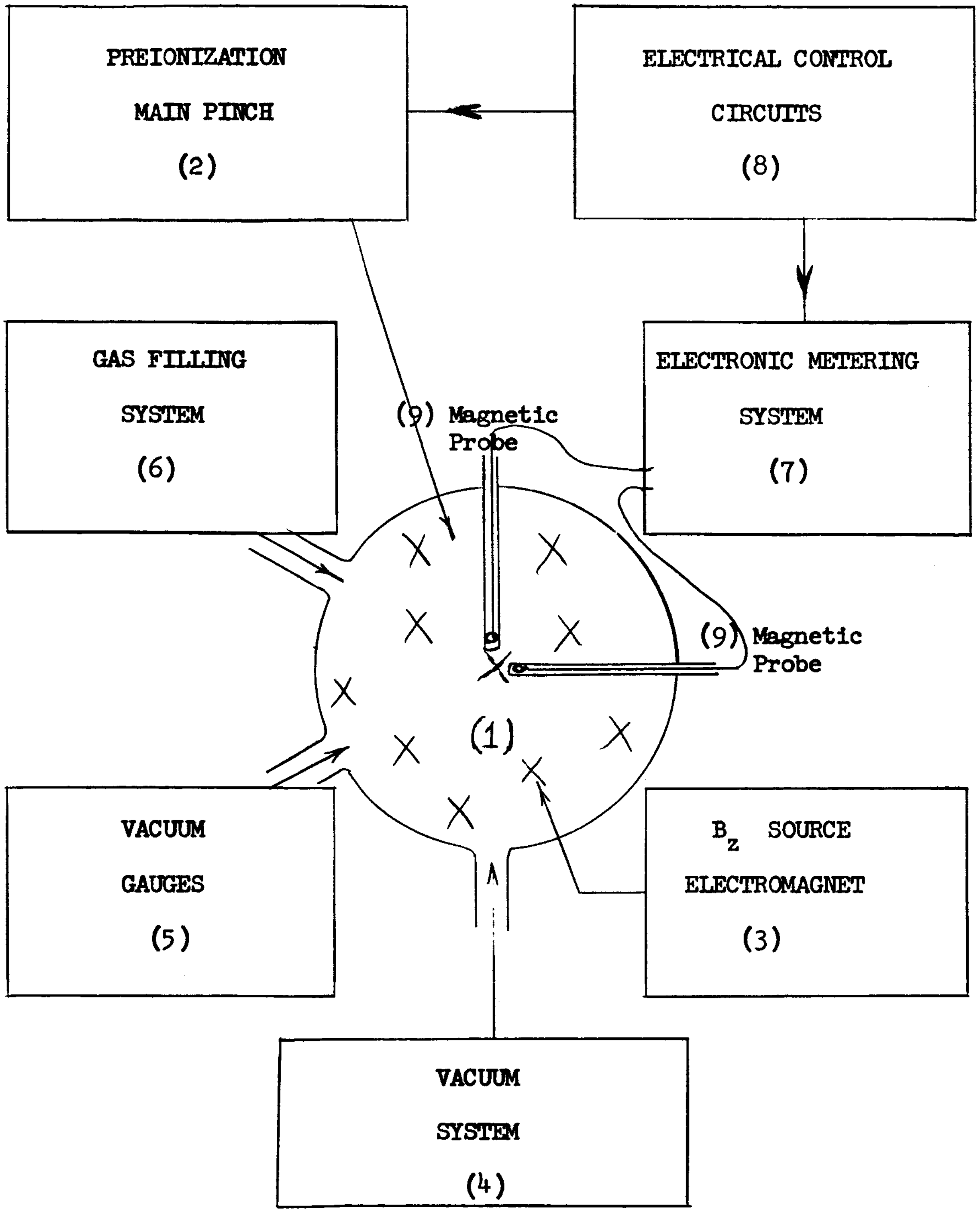
by magnetohydrodynamics between electrodes inserted into the path of the plasma is being considered. Also, Langmuir probes may be used as a possible method to observe the magnetosonic oscillations. With the present arrangement, there is little incentive to use microwaves. However, high speed Kerr Cell photography to study the current sheath is applicable and accessible in the laboratory. Piezoelectric probes for the detection of pressure fronts are also being considered.

E. Description of Major Components Now Being Used in this Experiment

In the present experimental arrangement, Fig. 1, used to study the dynamics of a current sheath and to search for magnetosonic oscillations, the following major items of equipment are now being used: (1) a metal and glass discharge tube, (2) a preionizing and a main accelerator capacitor bank, (3) an electromagnet for producing a stabilizing field, (4) a mechanical and an oil diffusion vacuum pump, (5) thermocouple, Pirani, and ionization gauges for measuring the vacuum and gas pressure, (6) a gas bottle, gas regulator, and control valves for supplying hydrogenic gas at low pressures, (7) oscilloscopes and electronic metering circuits, and (8) mechanical and electronic control circuits. These major components are discussed in the following sections.

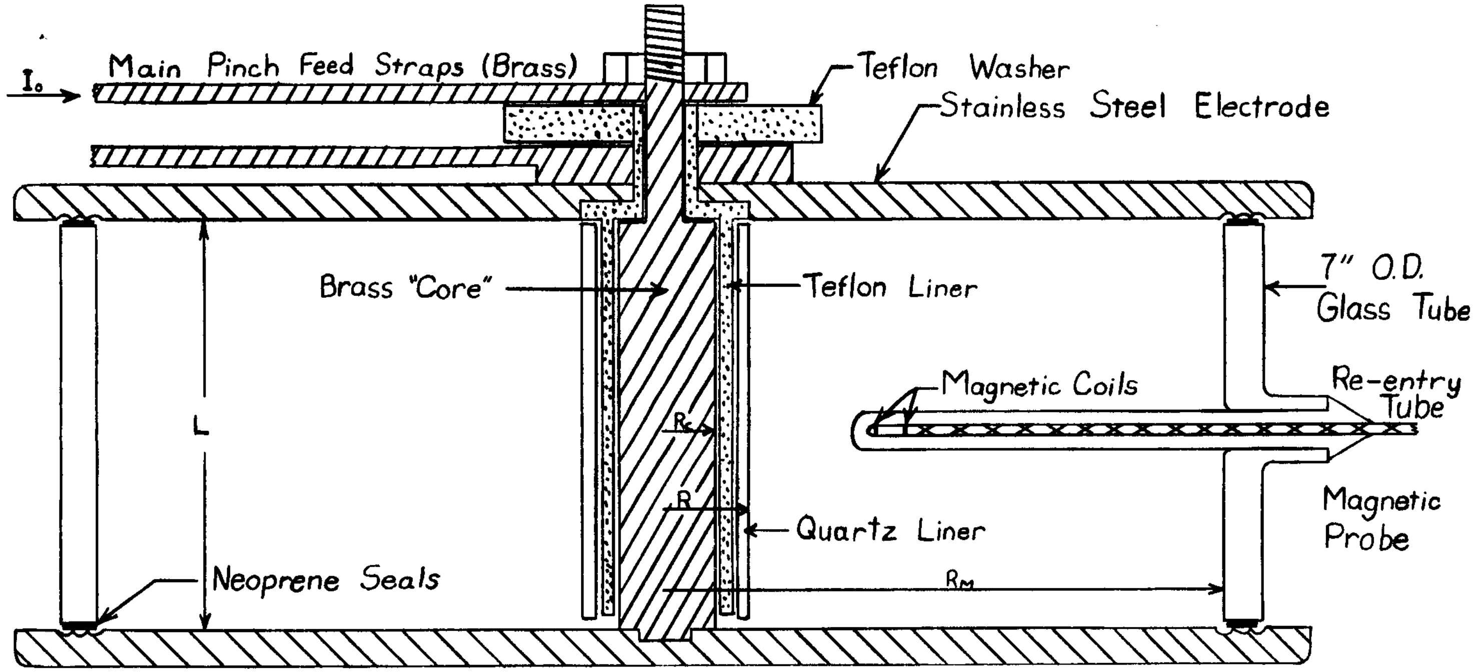
(1) Discharge Tube

A metal and glass discharge tube, Fig. 2, which is used to produce a dynamic current sheath in a crossed, steady, stabilizing magnetic field for studying a current sheath's motion and possible magnetosonic oscillations with magnetic probes has been designed, constructed, and



NOTE: Numbers refer to section headings where equipment is discussed.

Figure 1. BLOCK DIAGRAM OF EXPERIMENTAL APPARATUS to Study Dynamics of Current Sheaths and Magnetosonic Oscillations.



$R_c = 4.75$ mm $R_M = 0.095$ meter
$R = 7.0$ mm $L = 0.066$ meter
$I_o \doteq 10^5$ amperes

Figure 2. DISCHARGE TUBE
for
Current Sheath Dynamics and Magnetosonic Oscillations

is now being tested. The discharge tube has two stainless steel electrodes 9 1/2 inches O.D. and 1/2 inch thick connected at each end of a 7 inch O.D., 2 9/16 inch glass cylindrical bulb. Two small ridges are machined inside of a groove on a 7 inch O.D. diameter in the stainless steel electrodes for a seal from metal to glass. (Neoprene rubber seals are presently being used; Vitron O-rings are planned to be used in the near future.)

The 7 inch O.D. glass cylindrical shell, which may be seen in the photograph, Fig. 3, has three radial 15 mm I.D. glass tubulations and two radial 10 mm I.D. glass tubulations. One of the 15 mm tubes is connected to a 3 stage glass oil diffusion vacuum pump through a glass stopcock. A second of the 15 mm tubes is used to measure the pressure in the discharge tube by using a Pirani gauge tube. The third 15 mm tubulation is used for flowing hydrogenic gas into the discharge tube. The two 10 mm glass tubulations (attached radially and located with a 90° angular separation) are used for probing the current sheath.

A 0.375 inch O.D. brass "hard-core" current return is located on the main axis of the cylindrical arrangement and is used to set-up the fields required to drive the current sheath radially outward. The metal core is covered with a teflon cylinder for making the vacuum seal. The teflon is then shielded with a quartz tube inside the active plasma region between the stainless steel electrodes.

The main accelerating current input is through a 1/8 inch brass strap and current return is through a 1/16 inch brass strap. A quick-coupling coaxial cable header with positions for 10 low inductance cables is used to couple the capacitor bank to the discharge tube's input and output strap.

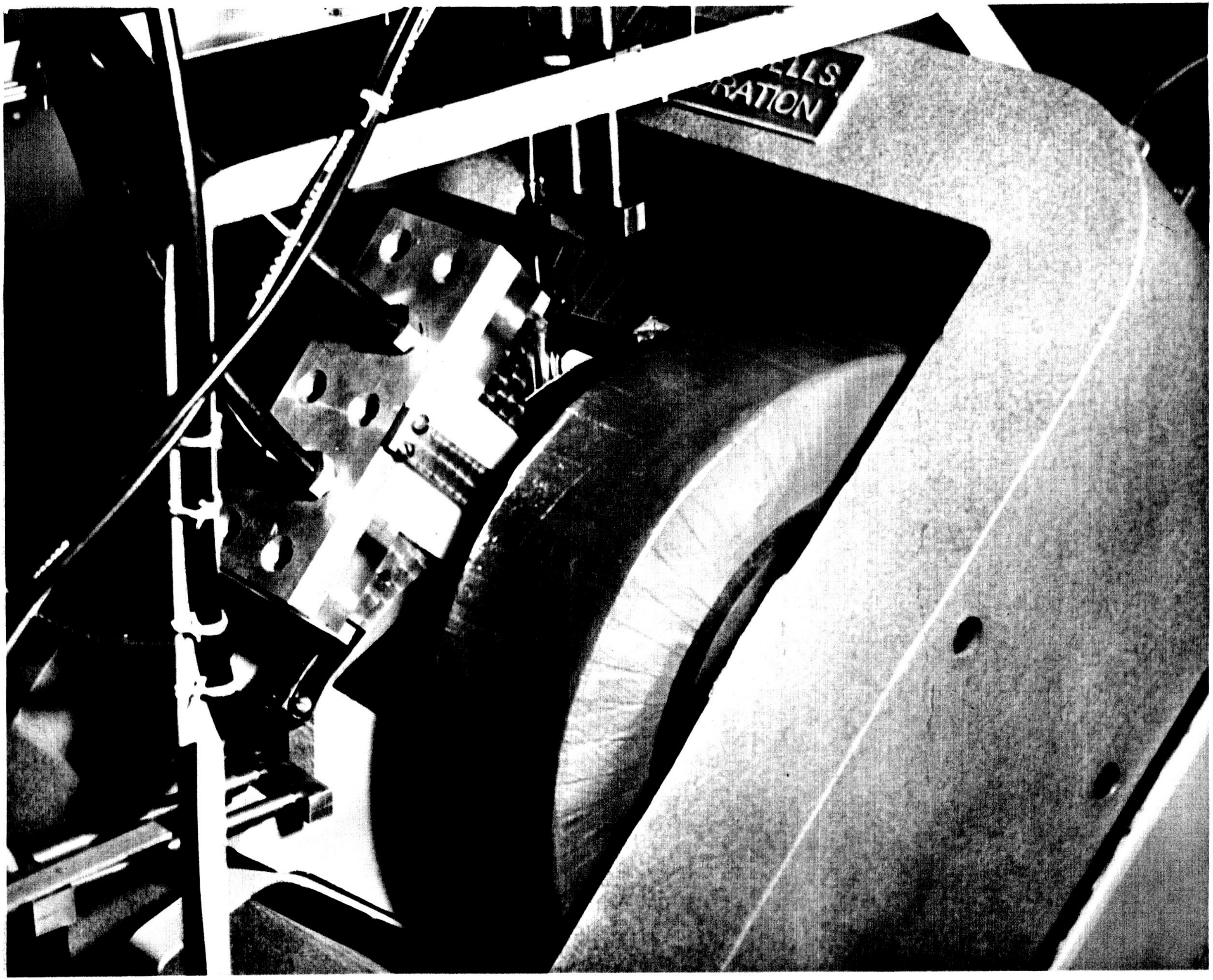


Figure 3. PHOTOGRAPH OF DISCHARGE TUBE IN ELECTROMAGNET
One radial magnetic probe is shown inserted in the vertical tubulation. The coax header is shown with only four cables attached.

Provision has recently been made to operate a linear discharge for preionization between the 9 1/2 inch O.D. stainless steel electrodes. Connections for the linear discharge will be made through several large wires from a 20 to 30 microhenry slowing-down inductor and through one strap of the main pinch header assembly. Brass straps are also placed around the glass discharge tube for possible radio frequency and/or 2 Mc capacitor discharge preionization.

(2) Preionizer and Main Accelerator

A linear discharge has now been assembled for preionization of the hydrogenic gas so that a reproduceable current sheath will be formed by the main accelerator. Two (or more) 20 KV, 15 μf, 3,000 joule capacitors are charged to 5 to 10 KV and discharged through a 20 to 30 microhenry inductor into the discharge tube via the steel electrodes. One side of the capacitors, when switched on, will be connected by several large No. 10 wires to one stainless steel electrode. The other side of the capacitors will be connected through part of the header assembly. With this arrangement, the peak currents are of the order of 10,000 amperes, with a ringing frequency of approximately 10 kc. (Refer to Table I for the parameters of the linear preionizer.)

Another method of preionization now being considered is that of a 20 KV, 2 Mc, radio frequency, 60 joule, capacitor unit consisting of 280 low inductance capacitors switched through a low inductance air-spark-gap switch. The 2 Mc capacitor unit may be linearly discharged through the electrodes into the gas or may possibly be applied to brass bands around the glass tube forming an azimuthal discharge.

TABLE I

PARAMETERS FOR LINEAR PREIONIZATION

Used in the Study of

CURRENT SHEATH DYNAMICS AND MAGNETOSONIC OSCILLATIONS

Number of Capacitors	Ringing Frequency	Period	Capacitor Voltage	Current Peak
1	7.8 kc	0.128 ms	5 kv	7,400 amps
1	7.8 kc	0.128 ms	10 kv	15,800 amps
1	7.8 kc	0.128 ms	15 kv	22,200 amps
1	7.8 kc	0.128 ms	20 kv	29,500 amps
2	5.5 kc	0.182 ms	5 kv	5,150 amps
2	5.5 kc	0.182 ms	10 kv	10,300 amps
2	5.5 kc	0.182 ms	15 kv	15,400 amps
2	5.5 kc	0.182 ms	20 kv	20,600 amps
3	4.5 kc	0.223 ms	5 kv	4,220 amps
3	4.5 kc	0.223 ms	10 kv	8,440 amps
3	4.5 kc	0.223 ms	15 kv	12,600 amps
3	4.5 kc	0.223 ms	20 kv	16,800 amps

TABLE II

PARAMETERS FOR MAIN ACCELERATOR CAPACITOR BANK

Used in the Study of

CURRENT SHEATH DYNAMICS AND MAGNETOSONIC OSCILLATIONS

Number of Capacitors	Ringing Frequency	Period	Capacitor Voltage	Tube Voltage	Current Peak
1	81 kc	12.3 μsec	20 kv	3.25 kv	140 k amp
1	81 kc	12.3 μsec	15 kv	2.44 kv	105 k amp
1	81 kc	12.3 μsec	10 kv	1.62 kv	70 k amp
1	81 kc	12.3 μsec	5 kv	0.81 kv	35 k amp
2	75 kc	13.3 μsec	20 kv	5.50 kv	259 k amp
2	75 kc	13.3 μsec	15 kv	4.13 kv	198 k amp
2	75 kc	13.3 μsec	10 kv	2.75 kv	130 k amp
2	75 kc	13.3 μsec	5 kv	1.38 kv	65 k amp
3	70 kc	14.3 μsec	20 kv	7.3 kv	369 k amp
3	70 kc	14.3 μsec	15 kv	5.48 kv	276 k amp
3	70 kc	14.3 μsec	10 kv	3.65 kv	183 k amp
3	70 kc	14.3 μsec	5 kv	1.83 kv	92 k amp
4	66.5 kc	15.1 μsec	20 kv	8.7 kv	466 k amp
4	66.5 kc	15.1 μsec	15 kv	6.5 kv	350 k amp
4	66.5 kc	15.1 μsec	10 kv	4.35 kv	234 k amp
4	66.5 kc	15.1 μsec	5 kv	2.17 kv	116 k amp

The main accelerator for forming and then driving the current sheath by $\vec{J} \times \vec{B}$ forces uses two or more 20 KV, 15 μf, 3,000 joule low inductance capacitors. This unit is capable of more than 100,000 amperes peak current with a full period of approximately 14 microseconds. These large currents are switched through two ingitron tubes per capacitor triggered by hydrogen thyratron tubes. The required charging supply is a 20 KV, 100 ma unit designed and constructed in our laboratory. (Refer to Table II for the parameters of the main accelerator.)

(3) Stabilizing Magnetic Fields

In order to stabilize, to slow down, and to even stop the outward motion of the dynamic current sheath, a strong external magnetic field applied normal to the motion of the current sheath's motion is required. As a result of the restoring forces established by the magnetic field, magnetosonic oscillations are expected to occur.

A Harvey-Wells Model L-75A laboratory electromagnet is used to supply the required 3 to 4 kilogauss fields across a 4 1/2 inch air gap which is 7 inches in diameter. A UR-1050 power supply manufactured by Harvey-Wells is used to furnish the 40 amperes d.c. current required to power the magnet.

A solenoidal magnet system with a working length of several feet is being obtained for use in the ion cyclotron and resonance studies. The 7 inch diameter of the working volume offers additional possibilities for other studies of current sheaths with longer cylindrical tubes.

(4) Vacuum System

In order to effectively study the dynamics of current sheaths, a vacuum system capable of a base pressure of 10^{-5} mm Hg or better is

required. (The present limitation in the ultimate vacuum base pressure is the organic seals in the discharge tube.)

The forepump used is a two-stage Duo-Seal Welch mechanical pump Model 1405 H, capable of 0.05 microns. The pump has a pumping speed of 33.4 liters/minute with the present motor drive speed. A three-stage Consolidated Vacuum Corporation Model GF-25 water-cooled, oil diffusion pump is now being used. The CVC pump has a 29 liter-second pumping speed and an ultimate vacuum capability of 8×10^{-8} mm Hg when using Octoil-S pump oil.

Except for the metal in the discharge tube, where the current sheath is formed, the system is constructed from Pyrex glass.

The control valves used on the present vacuum system are the following: a high vacuum, glass stopcock with a 15 mm bore, Corning # 7558, is used as the vacuum valve between the CVC diffusion pump and the discharge tube; a Corning # 7548 right angle stopcock is used in the forepump line to control the pumping speed of the forepump.

A liquid air trap, Cenco # 94005, with a Cenco # 15830-3 Dewar flask has been installed in the high vacuum line to trap diffusion oil back flowing from the CVC diffusion pump.

To obtain an initial seal of the metal electrodes with the glass bulb of the discharge tube, the electrodes are clamped through teflon rods. In order to eliminate vacuum seal problems at the magnetic probes (used to measure the magnetic field) positioned radially into the evacuated discharge tube, re-entry glass tubes several millimeters in diameter are used in the present study of the dynamics of the current sheath. Additional magnetic probes with small quartz tubes (the order

of 2 mm O.D.) driven through O-ring seals have been designed and some components constructed.

(5) Vacuum Gauges

Presently three different vacuum gauges are installed on the current sheath dynamics experiment. These gauges measure the forepressure, the base pressure, and the operating gas pressure. A RCA # 1946 thermocouple gauge is used to measure the forepressure at the imput of the CVC diffusion pump in the range of 1 mm Hg to 0.1 microns. A Pirani Pyrex gauge tube, CVC Type GAV-004, is attached to the discharge tube to measure the atmospheric to 0.1 microns range. A Veeco Type RG-75 ionization gauge is used to measure the base vacuum pressure; it is capable of measuring 10^{-3} mm Hg to 10^{-9} mm Hg.

(6) Gas Filling System

The hydrogenic gas to be used in the formation of a current sheath is presently supplied from a large commercial gas bottle through a two-stage pressure reducer and regulator. The gas is run through a liquid nitrogen trap (consisting of 3/16 inch O.D. copper tubing coils) into a Granville-Phillips Type C, ultra-high vacuum valve. The Type C valve is used to control the flow of hydrogenic gas into the discharge tube. From experience, this one Type C valve is adequate for controlling the flow rate of gas.

A cleaner system using small pure hydrogenic gas bottles and no pressure reducer is being considered. If a discharge tube without organic seals is constructed, very clean hydrogenic gas obtained by using a Palladium leak may be used to produce a purer hydrogenic current sheath.

(7) Electronic Metering

Presently a dual-beam, Tektronix Oscilloscope, Model 555, and a single-beam Tektronix oscilloscope, Model 535A, are available for recording electric signals. The magnetic probes being used each consist of two small coils; thus by using two such probes, four signals are available from each discharge. Magnetic loops are also used to meter the main current's peak value and the ringing frequency. A high voltage probe to measure voltages as high as 12 KV can be used to measure the voltage applied to the discharge tube.

A Veeco gauge controller, Type RG, is used to meter the ionization gauge. A circuit has been constructed to meter the emf generated by the RCA # 1946 thermocouple gauge. A Consolidated Vacuum Corporation multistation Autovac controller is used to meter the Pirani gauge.

(8) Electronic Control Circuits

The mechanical sequencing and the electronic delay circuits to control delays, charging cycles, and pulsing for the study of a dynamic current sheath consists of two units designed and constructed in the laboratory. The long delays (order of seconds) are controlled by a mechanical timer and relay circuit. The short delays of the order of several microseconds that are used between preionization initiation, main acceleration, and electronic recording initiation are generated by several electronic delay units constructed in the laboratory. A typical timing sequence for the experiment is shown in Fig. 4.

(9) Magnetic Probes

Small coils of #36 enameled wire wound on nylon rods 1/16 inch O.D. and machined to 50 mils are now being used to study the dynamics of the

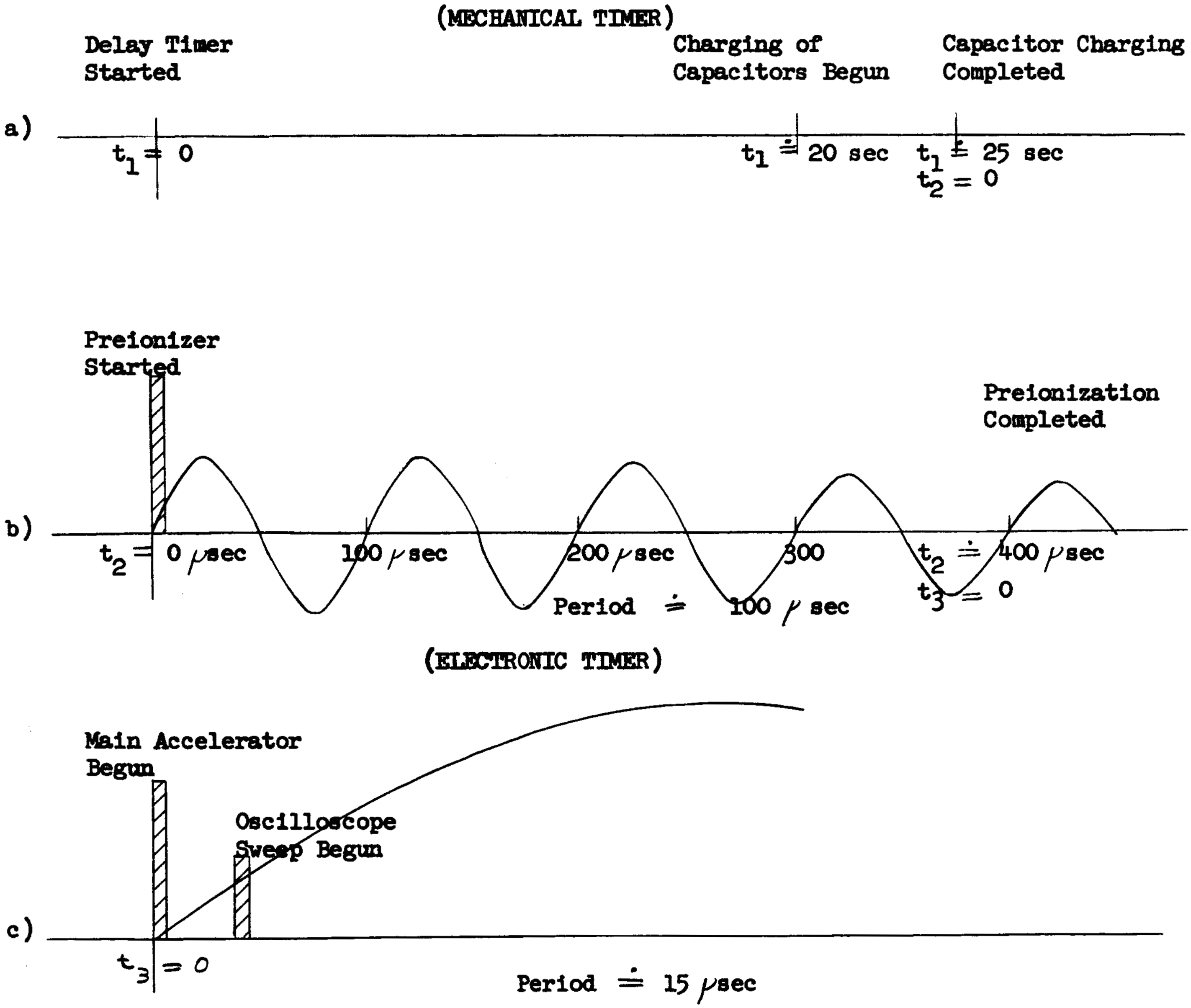
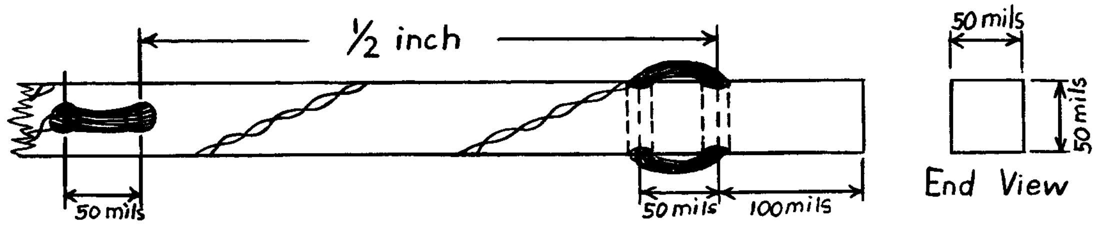
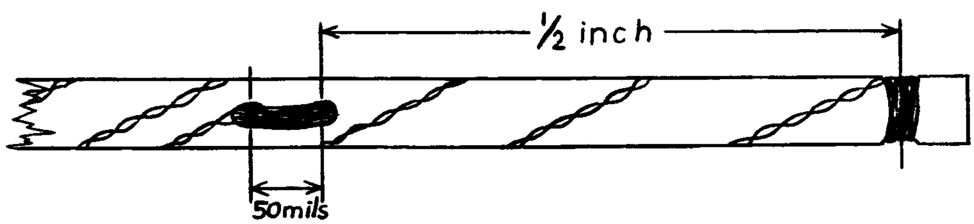


Figure 4. TYPICAL TIMING SEQUENCE for Study of Current Sheath Dynamics and Magnetosonic Oscillations

Type A To measure B_θ and B_z



Type B To measure B_θ and B_r or B_z and B_r



RC Integrator

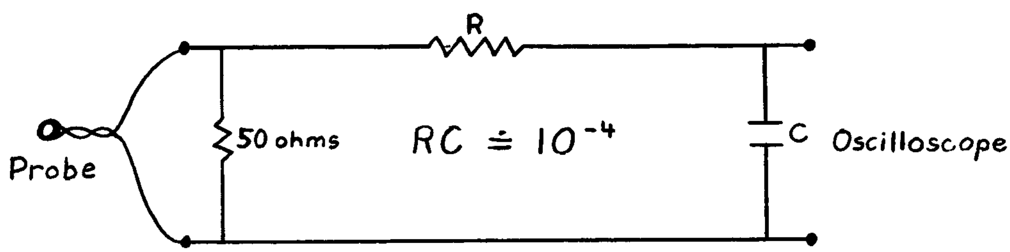


Figure 5 . MAGNETIC PROBES used in the Study of Current Sheath Dynamics and Magnetosonic Oscillations

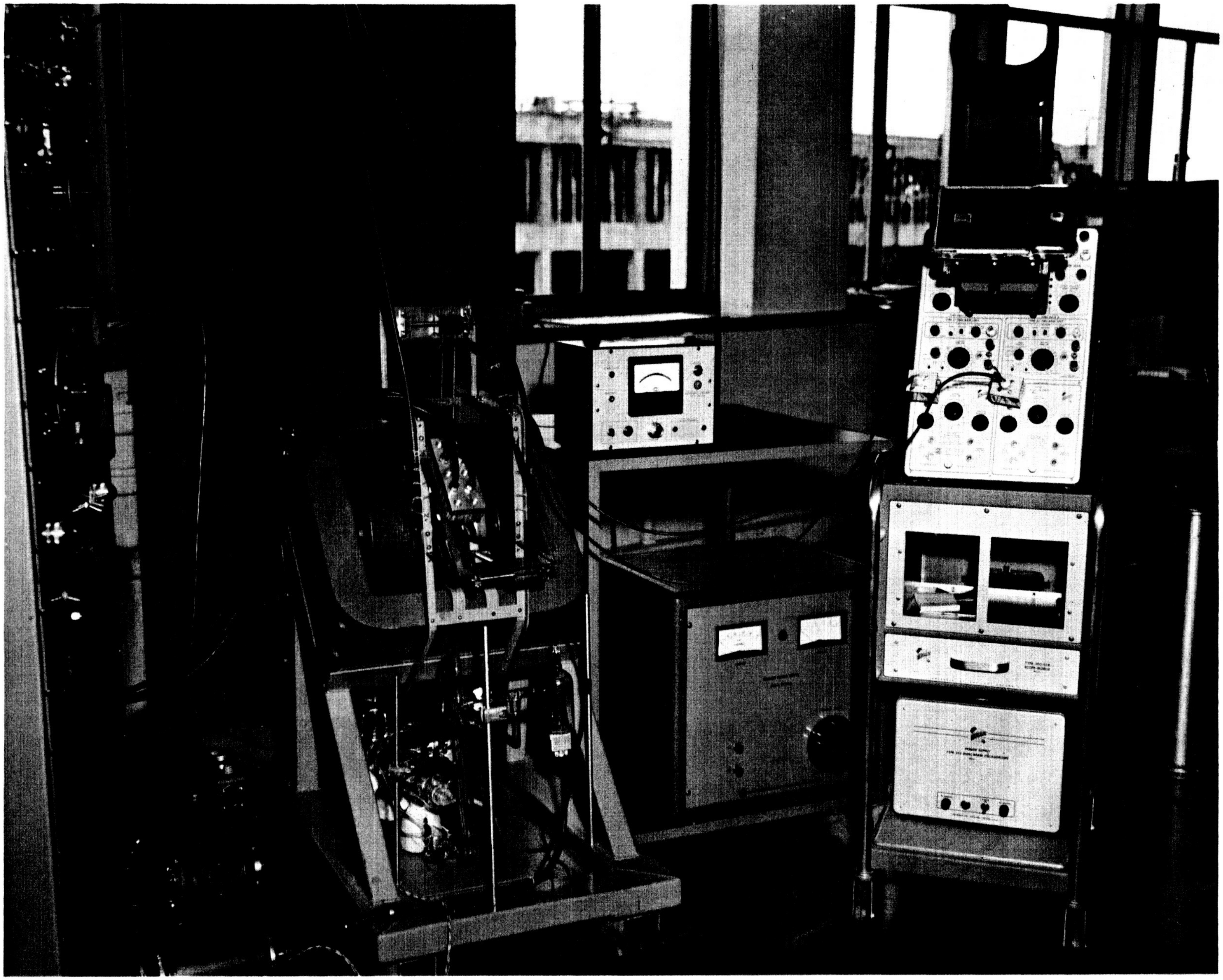


Figure 6. PHOTOGRAPH OF EXPERIMENTAL ARRANGEMENT used in the study of Dynamics of a current sheath. The mechanical timers and electronic control panel are shown on the far left. A seven inch electromagnet is pictured in the center, with discharge tube mounted in electromagnet. The mechanical and glass diffusion vacuum pumps are shown below and to the left of the electromagnet. Also shown are the Autovac vacuum meter, the electromagnet power supply, and a Tektronix model 555.

current sheath. One set of coils can be oriented to measure B_θ and B_z. Another set of coils to measure B_θ or B_z and B_r have been constructed. From the magnetic field information, the radius and velocity of the current sheath can be computed, and by employing Maxwell's em field equations, the current distribution can be calculated. Magnetosonic oscillations will, hopefully, be observed and interpreted by using these same magnetic coils. (See Figure 5)

A photograph taken of the experimental arrangement presently being used to study the dynamics of a current sheath is shown in Fig. 6.

II. Analytical Studies of a Current Sheath and Magnetosonic Oscillations

Presently, three aspects of a current sheath are being investigated analytically: (1) the dynamics of a highly ionized current sheath, i.e. the calculation of position and velocity, and other physical parameters as functions of time, (2) the formation of a current sheath, and (3) the stability of a current sheath with finite resistivity.

A. Numerical Calculation of Current Sheath's Position, Velocity and Possible Magnetosonic Oscillations

The position and velocity of a current sheath driven by $\vec{J} \times \vec{B}$ forces against restoring forces due to an external, axial magnetic field in an inverse pinch geometry have been studied using the "snow-plow" model of R. Garwin, A. Rosenbluth, and M. Rosenbluth.[4] Other models that have been investigated are the quasi-steady state or hydrodynamic model, slug model, and the gasdynamic model.

An equation of motion for the current sheath is derived from Newton's second law utilizing the "snow-plow" theory and Maxwell's field

equations. Restoring forces due to displaced axial magnetic flux lines and stretched magnetic field lines are also accounted for in the equation of motion, which may be written:

$$\rho\pi \frac{d}{dt}\left[(r^2 - R^2)\frac{dr}{dt} \right] = \frac{\mu_o I_o^2 \sin^2 \omega t}{4\pi r} - \frac{4\pi B_{zo}^2 (R_m^2 - R^2)^2 (r - R) r}{\mu_o L (R_m^2 - r^2)^2}$$

$$+ \frac{\pi B_{zo}^2}{\mu_o}\left[\frac{(R_c^2 - R^2)^2 r}{(r^2 - R_c^2)^2} - \frac{(R_m^2 - R^2)^2 r}{(R_m^2 - r^2)^2} \right].$$

The resulting second order, ordinary, nonlinear differential equation has been solved numerically using the Runge-Kutta method with Gill's Coefficients on a Control Data Corporation 1604, high speed, electronic, digital computer.[2] Velocities of the order of 10^7 centimeters per second for the case of zero external magnetic field have been found for the current sheath. The effects of various parameters on the dynamics of the current sheath, e.g. axial length, inner and outer discharge tube radii, pressure, and external magnetic field, have been investigated. Normalized curves for position have been computed and plotted. The position and velocity of the current sheath obeying the "snow-plow" theory have been computed for the present experimental arrangement.

When the external, stabilizing, magnetic field is of the order of several hundred gauss, magnetosonic oscillations have been predicted by the numerical solution. These oscillations have frequencies of the order of one megacycle for the present experimental arrangement. These oscillations are now being probed for experimentally.

When the external magnetic field is of the order of 3,000 gauss, the computed curves of position for the current sheath indicate that

the sheath will be slowed down and stopped.

From experimental data obtained by Dr. Dougal, Mr. Poeschel, and Mr. Kittoe at the University of Illinois,[6] correlation results from experimental measurements of the current sheath's properties with the "snow-plow" theory.

B. Boundary-Layer Formation for the Current Sheath

An analytical study of the formation of the current distribution and other plasma properties in a cylindrical discharge with plasma inside an annulus and with a line current located along the central axis, which corresponds to the physical arrangement now being used to produce the dynamic current sheath experimentally, is now in progress. The present investigation is an extension of the study of boundary-layer formation begun by N. W. Wyld and K. M. Watson[9] and continued by S. A. Colgate, J. Killeen, and G. Gibson.[1] The dependent variables are: the current density, the resistivity, the electron and the ion temperatures, the degree of ionization, and the electron and ion densities. The independent variables are the radial position coordinate and time.

Some of the assumptions made are the following: (1) the steady, externally applied magnetic field is much stronger than the driving magnetic field, (2) heat diffusion across the magnetic field lines can be neglected, (3) mass motion can be ignored during formation of the boundary-layer, (4) the energy change of neutrals can be ignored, (5) bremsstrahlung losses can be neglected, and (6) charge-exchange can be neglected.

By using electromagnetic field equations and dynamical plasma equations, a system of partial differential equations can be written to describe the current density, resistivity, electron and ion temperatures, and degree of ionization as a function of radius and time. Two field equations of Maxwell and an Ohm's law are used. The plasma equations employed are: (a) an energy balance equation, (b) an equation relating resistivity to collisions, (c) an ionization equation, and (d) an energy transfer equation.

The resulting set of partial differential equations has been coded for machine computation on a CDC 1604 high speed, electronic, digital computer using finite difference techniques. Presently, the code is being checked out.

C. Preliminary Work on Stability for the Finite Resistivity Plasma

Several physical geometries that are hydrodynamically stable in the infinite electrical conductivity limit are presently being studied by other research laboratories, e.g. the cusp arrangement, the Levitron which is a torodial hard-core pinch, the straight inverse pinch, and the Triaxial pinch which is stable for all higher order modes. We recall that the simple hydrodynamic stability criterion may be stated, "to be hydrodynamically stable, magnetic flux lines must be convex to the plasma". This condition is met in the inverse pinch where the <u>driving</u> magnetic field, B_θ , is convex to the plasma.

Instabilities have been observed in configurations that were predicted to be hydrodynamically stable using infinite electrical conductivity theory. Thus, the instabilities might be non-hydrodynamic

in origin, e.g. due to finite Larmor radius effects, microinstabilities, etc., or due to resistive effects. The aspect of resistive effects is now being considered here.

Several excellent papers have recently been published on the finite-resistivity instabilities. To mention only a few, one by H. P. Furth, J. Killeen, and M. N. Rosenbluth;[3] one by J. L. Johnson;[5] and two by L. C. Woods.[7,8]

Three basic types of finite resistive instabilities have recently been studied by Drs. Harold Furth, John Killeen, and Marshall Rosenbluth for a plane current layer. These have been called the "tearing" mode, which is a long-wave breakup of the layer along current-flow lines, the "ripple" mode, which is due to resistivity gradients in the layer and, thirdly, the gravitational interchange mode that develops for the case of finite resistivity with finite magnetic shear.

The "tearing" mode has been demonstrated in a theta pinch experiment at Aldermaston. The present experimental arrangement used to study the dynamics of a current sheath, an inverse pinch, has certain advantages for the study of finite resistivity instabilities. For certain vacuum B_θ and external B_z field configurations, the "tearing" mode and the "rippling" mode can be inhibited. This author hopes to continue study of finite resistive instabilities as applied to the present geometry used to generate the dynamic current sheath.

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